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PATENT SPECIFICATION

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(54) RETROREFLECTIVE TRANSPARENT SPHERES OR BEADS

(71) I, LUDWIG EIGENMANN, of Swiss Nationality, of Vacallo, Canton Tessin, Switzerland, do hereby declare the invention, for which I pray that a Patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention is concerned with the art of forming and making use of retroreflective transparent spheres or beads which, properly associated with light reflective or light diffusive layers or pigments, and partially embedded within a suitable support, impart to the surface of roadway marking signs or of advertising signs the property of reflecting light back to the source of incident light.

The term retroreflector is hereinafter used to designate a reflective element which essentially has a transparent sphere or bead and which will reflect an incident beam or ray of light in such a manner that a brilliant cone of light is returned to the source even though the incident light strikes a surface on which such spheres or beads have part-spherical concave surfaces exposed to the light and within which reflective or diffusive layers or pigments are adjacent to the embedded portion of the spherical surface of said spheres or beads.

The art of forming and of making use of such retroreflective beads is a well worked one and a wide patent literature is available thereon. The typical mode of operation of such beads comprises refractively focusing an incident light beam on a point on the spherical surface of the bead and then reflecting such beam back along a path substantially parallel to its own incident path. Acording to well-known principles of optics, such retroreflection occurs when the index of refraction of the transparent material, of which the sphere or bead is made, is comprised between about 1.90 and 1.95 (such index being conventionally indicated by the symbol "n_D"). The light rays that can be retroreflected are those which impinge on a part-spherical concave surface portion the angular width of which is not greater than about 74°. The rays which impinge on the exposed portion of the bead, beyond the confines of said part-spherical portoin, cannot be properly focused within the bead and they are therefore dissipated. Therefore, not more than about 25% of the light which actually impinge on the bead can be retroreflected.

A rather extensive analysis of retroreflection by known retroreflective beads can be obtained for example from the British Patent Specification No. 1,343,196 of the same Applicant.

The optical efficiency of such known retroreflective transparent spheres is however undesirably low. An important reason for such low efficiency is that a portion of the impinging light is outwardly reflected instead of being inwardly refracted at the sphere-air interface. An important parameter to be taken into account is the transparency factor, conventionally indicated by symbol "T", and given by the expression

$$T = \frac{\text{transmitted light}}{\text{incident light}}$$

wherein the "transmitted light" and the "incident light" indicate quantities of light energy measured in conventional manner such as photometrically. This parameter is a ratio and the value of T obtained is independent of the mode of measuring, provided that said mode is applied consistently to the incident and transmitted lights, and is independent of the absolute values of the measured lights.

The value of such transparency factor is approximately proportional to the index of refraction between the substances defining the interface traversed by the refracted light ray, that is, generally the index of refraction between the glass which forms the bead and the adjacent air.

The present invention has for its object to provide a new and surprisingly efficient transparent retroreflective sphere which is not subject, or is greatly less subject, to the above limitations, and by which the retro-

reflectivity of a sign or marking using such spheres is surprisingly optimized.

According to the present invention, a retroreflective transparent sphere consists of an optically non-homogeneous spherical transparent body comprising a core of transparent material having its diameter greater than half of the diameter of the body, and an outer portion about said core, the core having a refractive index between 1.595 and 1.62, the outer portion having a refractive index between 1.47 and 1.52, and the transparency factor "T" of the outer portion of transparent material in air, as herein defined, being greater than 75%.

Preferably the core is optically homogeneous, and its refractive index is not less than 1.6.

The outer portion may be composed of a plurality of concentric layers, each layer having a refractive index which is lower than that of the next inner component.

The core may be of glass but with an outer portion of polymeric material.

Nonhomogeneous spheres, or overall diameter from 0.1 to 3.0 millimeters, for example, can be made use of for advantageously replacing the current homogeneous spheres in various retroreflective compositions, structures and markings or signs.

These and other features and advantages of the invention will be apparent from the following detailed disclosure, of preferred embodiments of the invention, taken together with the accompanying drawings, wherein:

Figure 1 is a diagrammatical sectional view of a conventional homogeneously transparent prior art sphere, of index of refraction $n_D=$ about 1.92, and illustrates the optical behaviour thereof;

Figures 2 and 3 are similar views of two-component spheres produced according to the invention, and illustrate their optical behaviours;

Figure 4 is a detail, on a larger scale, of the sphere of Fig. 3;

Fig. 5 is a graph showing two curves one of which represents the characteristics of a prior art sphere while the other represents the characteristics of a preferred embodiment.

While a structure having a controlledly variable index is somewhat difficult to manufacture (even when making use of suitable transparent polymeric materials), a very satisfactory article can be provided by a nonhomogeneous structure including concentric layers of different index of refraction, thereby providing a stepped curve (having as many steps as there are layers).

Referring now to Fig. 1, there is shown a homogeneous sphere according to prior art, having an axis A—A, and which is assumed to be made of a suitable optical glass of $n_D=1.92$, and to be impinged by a beam of parallel light rays. A relatively small bundle 12 of such rays, impinging on a part-spherical concave surface of width about one-third of the diameter of the sphere, is focused at one point 14 on the axis A—A. A certain amount of other rays, impinging as shown at 16 on a part-spherical concave surface of width half of the diameter of the sphere, is also approximately focussed. The remaining part of the beam is dissipated by outward reflection, on the surface of said sphere of high index of refraction.

Consider now the sphere of Fig. 2, produced according to the invention, including a spherical core 20 and an outer portion 22, the diameter of the core being about two-thirds that of the sphere. According to this example, the core consists of a suitable glass of $n_D=1.595$ and the outer portion of a glass $n_D=1.52$. Such outer portion 22 can be therefore advantageously formed with the well known, economical and stress and weather resisting window pane glass. The rays impinging on a part-spherical portion of width 0.9 of the diameter of the sphere can be refracted therewithin. Most of the focussing occurs at a point *P* spaced externally from the surface of the sphere. Such arrangement is useful when the sphere is associated with reflecting means considerably spaced from said surface, according to known arrangements.

The sphere of Figs. 3 and 4 has a core 30 of $n_D=1.62$ and one outer portion of $n_D=1.47$. Most of the refracted rays, focus very near to the surface of the sphere, on the axis A—A of the sphere and of the beam.

Transparent polymeric materials, such as polyurethane and polyester resins can be made use of for forming the portions 22 and 32 of the embodiments of Figs. 2 and 3, if desired.

The striking improvement provided by the invention in the art is demonstrated by the curves of Fig. 5, which illustrates the optical efficiency *E* plotted against the index of refraction n_D of various spheres. Optical efficiency indicates the ratio of reflected light energy to impinging light energy, and takes into account not only the transparency factor but any other cause of light dissipation. The optical efficiency *E* has been calculated and experimentally verified by taking into account any factor which influences the ratio between impinging light and properly focused and retroreflected light, that is the reflection to the exterior (which is proportional to the index of refraction at the surface) and the correctness of the focusing.

The curve *I* corresponds to the prior art homogeneous sphere of Fig. 1 and has its peak for $n_D=1.92$. The curve *II* is representative of a two-component nonhomogeeous sphere, such as those of Figs. 2, 3 and 4. Said sphere, having a core of $n_D=$

about 1.67, has an efficiency E five times greater than that of a prior art homogeneous sphere of equal index of refraction.

WHAT I CLAIM IS:—

1. A retroreflective transparent sphere consisting of an optically non-homogeneous spherical transparent body comprising a core of transparent material having its diameter greater than half of the diameter of the body, and an outer portion about said core, the core having a refractive index between 1.595 and 1.62, the outer portion having a refractive index between 1.47 and 1.52, and the transparency factor "T" of the outer portion of transparent material in air, as hereinbefore defined, being greater than 75%.

2. A retroreflective transparent sphere, as claimed in claim 1, wherein said core is optically homogeneous, and its refractive index is not less than 1.6.

3. A retroreflective transparent sphere, as claimed in either of claims 1 and 2, wherein said outer portion is composed of a plurality of concentric layers, each layer having a refractive index which is lower than that of the next inner component.

4. A retroreflective transparent sphere, as claimed in any one of claims 1 to 4, wherein said core is of glass and said outer portion is of polymeric material.

5. A retroreflective transparent sphere substantially as described herein with reference to figs. 2, and 5, or to figs. 3, 4, and 5, of the acompanying drawings.

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2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig.1

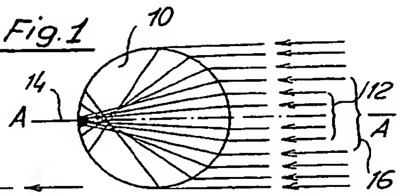


Fig. 2

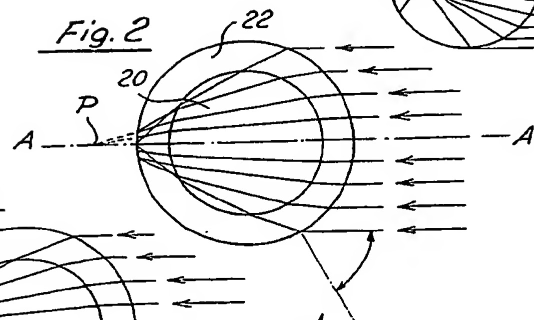


Fig. 3

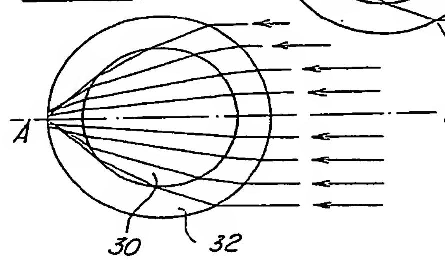
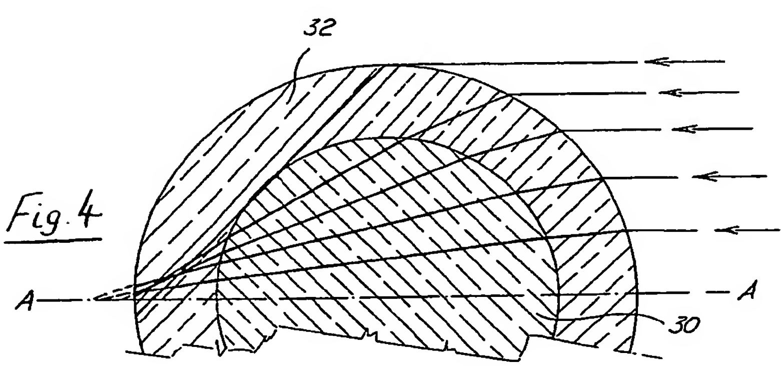


Fig. 4



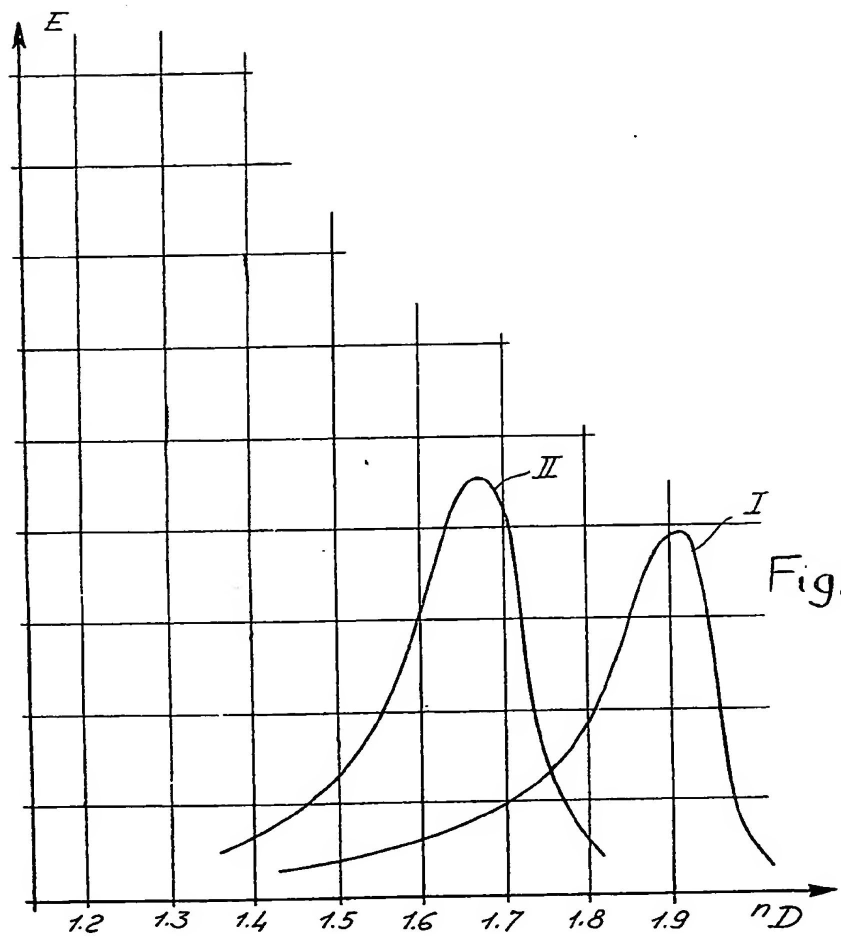


Fig. 5